SEAWASP: REFRACTIVITY CHARACTERIZATION USING SHIPBOARD SENSORS

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Introduction

A companion paper (Reference 1) contains an overall description of the SEAWASP (Shipboard Environmental Assessment/WeApon System Performance) system. The initial goal of the system is to characterize, in real time, the effect of the environment on AN/SPY-1 radar performance. The system consists of two primary parts, a radar performance component and an environmental characterization component. The purpose of this paper is to describe the environmental characterization component.

Overall System Description

The major purpose of the environmental measurement system is to produce a profile of modified refractivity from the surface to a 350 m altitude and automatically output this profile to the radar performance assessment portion of SEAWASP. To produce these refractivity profiles, the environmental portion of the system must make detailed measurements of meteorological parameters. Although the system was designed for the purpose of generating refractive index profiles, it has proven to be a general purpose tool for gathering detailed meteorological measurements aboard ships,

In order to accurately describe the profile of modified refractivity from the surface to a 350 m altitude, two different techniques are required, The lower region extending from the surface to an altitude of some tens of meters, frequently contains an evaporation duct and must, in general, be modelled utilizing time-averaged bulk meteorological measurements, (Reference 2). The upper region, extending from the top of the evaporation duct region to 350 m must, in general, be measured (Reference 3). The two separate profiles must then be merged with great care to avoid generating false artifacts that would cause unrealistic radar propagation calculations,

In the case of the SEAWASP system mounted on AEGIS class cruisers, the bulk measurements are made with fixed sensors mounted on the ship at a height of 9 m to measure atmospheric pressure, temperature, relative humidity, relative wind speed and direction, and infrared surface temperature, In addition, accurate measurements of air temperature and relative humidity at a height of 2 cm and surface water temperature at a depth of lcm are made with a disposable telemetering float periodically thrown overboard (Reference 4). The upper region is directly measured with a rocketsonde. The rocketsonde is periodically fired from the ship, ascends to an altitude of roughly 800 m and telemeters temperature, relative humidity and pressure back to the ship as it descends to the surface. Figure 1 shows an overall block diagram of the environmental measurement system.

Sensor Location Considerations

Airflow over the ship can cause serious contamination of the meteorological measurements. In addition, the location of the meteorological sensors must not have a negative impact on existing weapons systems or ship operations. Also, bulk measurements used for evaporation duct modeling (Reference 2) must be made at a relatively low altitude. These constraints have limited the locations available for mounting **SEAWASP** sensors, In our case the superstructure is too high, The fantail and bow have guns that do not allow fixed sensors to be used on these decks. The flight deck is not suitable because of a hazzard during flight operations. The optimum location for meteorological sensors on AEGIS class cruisers is the aft VLS (Vertical Launch System) deck. This deck has few obstructions that interfere with airflow across the sensors,

The wake from the ships superstructure, which is dependent on wind speed, wind direction, ship speed and ship heading, may cause serious measurement contaminiation for sensors located on the aft VLS deck. It has been found that uncontaminated measurements are obtained when the relative wind speed across the sensors is above 2 knots and the wind direction relative to the ships longitudinal axis is between 15 and 170 degrees for sensors mounted on the starboard side and 190 and 345 degrees for sensors mounted on the port side. For this location dual sensors have been found to supply satisfactory data for 75% of the time on average. A quick analysis shows that if the ship were dead in the water and the wind were blowing at a speed above 2 knots, we would expect good data for 86% of the time. If the ship were underway at a speed of 10 knots with a 10 knot wind we would expect good data for 77°/0 of the time.

Detailed System Description

A detailed block diagram of the system is shown in Figure 2. The system has three fixed sensor locations, A sensor suite located on the starboard side of the VLS deck is used to measure air temperature, relative humidity, pressure, relative wind speed and direction, ship compass heading and ship position using GPS (Global Positioning System), Water temperature is measured with a downward pointing pointing IR (infrared) thermometer. A small handheld launch control terminal is connected by a short cable to the starboard sensor box and serves to give the operator launching rocketsondes or floats necessary inputs to and feedback from the computer controlling the telemetry receiver. A second sensor suite located on the port side of the VLS deck is used to measure air temperature, relative humidity and relative wind speed and direction. The antenna used to receive telemetry signals from the rocketsonde and floatsonde is also at this location. The third sensor location is in the AN/SPY-l radar aft cooling water pump room where we measure sea water temperature at the inlet to the radar cooling water supply.

Analog signals in the port sensor box are digitized and multiplexed into a single RS-422 data stream. This port signal is routed through a junction box to the starboard side where a microcontroller digitizes analog signals from sensors in that box, multiplexes them with the outputs of digital sensors and the launch control terminal. The output of the starboard sensor box thus contains, in one RS-422 data stream, the multiplexed outputs of the port and starboard boxes and launch control terminal, This data stream is routed through the junction box to an IBM-compatible notebook computer which communicates via an ethernet link to the radar performance assessment portion of the SEAWASP system. Communication from the computer back to the starboard box is also possible and is used to change configuration of the starboard microcontroller, and do such tasks as calibrating the compass and communicating with the launch control terminal. The water temperature sensor in the radar cooling room is digitized and routed through the junction box to the computer along an RS-485 line. RS-485 was chosen for this purpose since it allows multiple low data rate sensors, that maybe located some distance from each other, to be connected in parallel along one data line and separately interrogated by the central computer. Future expansion of the - system will probably be done using this RS-485 line,

A power supply in the junction box supplies the low current 12Vdc to the sensors and contains a preamp for the telemetry antenna. The signals and 12Vdc power are run to all sensor locations and the computer along a 6 shielded pair cable. This cable has a bus structure so that any signal is available at any location. Photographs of the interior of the port and starboard sensor boxes are presented in Figures 3 and 4, respectively. Figure 5 is a photograph of the sensors mounted on the AEGIS cruiser USS Anzio (CG-68), Two types of disposable sensors are used in the SEAWASP system. The first of these is the floatsonde (Reference 4). This sensor is a small 1.25 inch diameter x 12 inch long device which is thrown overboard and telemeters measurements of surface air temperature, relative humidity and water temperature back to the ship for use in evaporation duct calculations. A photograph of the sensor is shown in Figure 6. The second disposable sensor, a rocketsonde, is periodically launched from the ship to an altitude of 800 m and telemeters back to the ship measurements of temperature, relative humidity and pressure as it descends from apogee to the surface. Measurements with the 2.5 inch diameter x 28 inch long cardboard rocketsonde are made at 1 second intervals which corresponds to a vertical resolution of 2.5 m, A photograph of the rocketsonde components is shown in Figure 7. A photograph of the rocketsonde in its launcher with the ignition box and handheld launch control terminal is shown in Figure 8,

Software Features

The SEAWASP data acquisition program is run in a multitasking environment on an IBM-compatible notebook computer under the OS-2 operating system, The software is designed to run at system power up with no operator assistance with all applications running, Initial setup including calibration and tailoring the system to individual ship configurations is menu driven with intervention of an operator. Thereafter, all operation can be automatic with operator intervention only required to fix hardware trouble reports displayed on the workstation or to answer questions regarding rocketsonde and floatsonde launches displayed at the handheld launch control terminal,

-Measured Parameters

The computer makes a determination in realtime if the relative wind speed at the sensors is above 2 knots and the wind direction is in the range of 15-170 degrees for the starboard sensors or 190-345 degrees for the port sensors. If these conditions are met for the majority of a 5 minute period, data is considered valid and uncontaminated by the ships wake, Air temperature and humidity from the appropriate sensor suite, sampled at a 2 second rate, is averaged for a 5 minute period. At times, however, the ships course and the true wind vector will not be suitable, and no average will be calculated. IR water temperature, compass heading, ship GPS course, ship position and relative wind vector are also averaged for the 5 minute period. For the rocketsonde case, air temperature, relative humidity and pressure are measured and recorded at a 1 second rate as the instrument package descends from apogee to the surface. Air temperature, relative humidity and water temperature are measured and recorded at 1 second intervals by the floatsonde. Time used by the system is GMT time synchronized to the GPS receiver.

-Calculated Parameters

Ship compass heading is automatically corrected for local magnetic declination at the current ship position by the computer. The compass is also corrected for changing magnetic anomolies caused by the steel-hulled ship based on an algorithm using the GPS receiver, The corrected compass data along with ship heading from the GPS receiver and average relative wind vector is used to calculate the true wind vector. The averaged ship data, by itself, or at times in conjunction with surface air temperature, relative humidity and water temperature from the floatsonde, is used in a calculation of the modified refractivity profile in the evaporation duct. The rocketsonde pressure data is used to calculate altitude, while temperature, pressure and relative humidity data are used with the altitude calculation to calculate the profile of modified refractivity to an altitude of 350 m. These two profiles are carefully spliced to produce a single profile for the radar performance assessment component of SEAWASP running on HP 7431 processors.

-Engineering Realtime Display and Playback Capability

Realtime and post processing data analysis features have been built into the software for research and engineering purposes. All measured and calculated data may be recorded on the hard drive of the notebook computer. Plots or tabulations of all data, including the results of model calculations, rocketsonde refractivity profiles, and location of all data samples acquired plotted on a detailed world map are available in realtime or by playing back data taken previously, Realtime display of all sensor outputs is available in table form or time history plots. A compass rose with simultaneous display of corrected compass heading, ship course, relative wind direction from both starboard and port sensors, along with results of the most recent true wind direction is available. All displays maybe viewed individually or windowed with other displays. Viewing of current data or analysis of previous data does not interrupt realtime data acquisition or calculation capability. Further, these data are potentially available to the SEAWASP display in CIC (Combat Information Center) if they are found to present insight into phenomena that impact combat system performance.

Evaporation Duct Models

Most existing models tend to overestimate the height of the evaporation duct, on the average. This can be serious problem when they are used to predict weapon system performance. Overestimation of the evaporation duct height usually produces an unrealistically y large detection range for low altitude targets. Reference 2 describes the model on which our work was based, In general, evaporation duct models use time averaged inputs of temperature, humidity, and wind speed at some reference height near the top of the evaporation duct along with an estimation of temperature and humidity at the surface boundary. Most models use water temperature as a measure of surface air temperature and assume a value of 100°/0 relative humidity for the surface value, Reference 2 also does not account for the effect of humidity on air density although this is often not a large effect, All models should use virtual temperature in their calculations. Virtual temperature is defined as the temperature that a parcel dry air would need to have to be of the same density as a parcel of moist air at the same pressure. At times most models exhibit a large sensitivity to input measurements and and their calculations tend to become unstable when the atmosphere is stable ie when the surface virtual temperature is cooler than the virtual temperature at the reference height especially in the presence of low winds. Most of the time the air over the ocean surface is slightly unstable, When the atmosphere is unstable large variability in the measurements is observed. No technique is available for making a direct measurement of the refractivity profile in the evaporation duct region under these conditions. When the atmosphere is stable, however, the atmosphere tends to be non-turbulent and a direct measure with high resolution instruments such as the rocketsonde is possible. This characteristic is fortunate, for when the models break down under stable conditions, direct measurements work best, Unfortunately, it is easy to make continuous calculations of the evaporation duct with fixed sensors in unstable conditions, but in stable conditions the evaporation duct must be directly measured with disposable sensors and continuous measurements are impossible.

Two evaporation duct models are currently being used for calculation of the modified refractivity profile in the evaporation duct. Both models are based on work described in Reference 2 with the incorporation of several modifications. Both models use virtual temperature in all calculations. The first model assumes that the atmosphere is neutrally stable with a constant virtual temperature profile within the evaporation duct, A controversial empirical method is used m this model to calculate the surface humidity from the humidity measured at the reference height so that only inputs of temperature and relative humidity at the reference height are required to model the evaporation duct. Since the model only works in neutral or slightly unstable conditions, a rough measurement of water temperature is required to insure that region is not very stable; ie water temperature is not much cooler than temperature at the reference height. This model is very robust and not subject to calculation instability or overestimation of the duct height. It does, however, tend to underestimate duct height and can be thought of as supporting conservative radar performance assessments. This model can run continuously with only fixed sensor inputs. The second model uses true windspeed, temperature, and relative humidity measured at the reference height with fixed sensors, as well as surface air temperature and relative humidity measured at the surface with the disposable floatsonde. While this approach is controversial, it has been found to better characterize the evaporation duct. Unfortunately continuous measurements at the surface are impossible since they require expendable sensors. Use of the floatsonde does, however, provide a non controversial sanity check on the presence of an evaporation duct. If the measured refractivity at the surface is less than the refractivity at the reference height, subrefractive conditions exist regardless of model calculations, Present operation of the SEAWASP system automatically picks the best model based on the availability of timely data.

Practical Considerations

The shipboard environment is particularly hard on meteorological sensors. A number of engineering problems have been overcome in order to meet the system design lifetime of 1 year without operator-assisted calibration or routine maintenance other than a weekly fresh water washdown. A few of the problems encountered and their solutions are described: 1. Corrosion is a serious problem. All SEAWASP topside components are made of plastic, fiberglass, titanium or in a few areas, stainless steel. No surfaces are painted. 2. High RF power densities are often present. All topside electronic components are RF shielded and analog sensors are digitized at the sensor to avoid noise pickup. 3. Shipboard cable runs are often complicated so sensor signals are multiplexed where possible. 4. IR sensor apertures must be protected from salt spray. We use a thin polyethylene window material for our 8-14 micron sensors commonly available as Glad Cling Wrap. This is treated with Rain-X to shed water droplets that would otherwise contaminate the sensor readings, 5, R. M. Young Corp, manufactures the most widely used radiation shield that is required to reduce temperature and humidity sensor heating from direct sunlight. This shield has an unnecessarily restricted airflow that causes errors at low winds. This unit must have spacers installed between shield plates. 6. In damp situations (common aboard ship) the aforementioned shield becomes wet and causes the humidity sensor to overestimate relative humidity. The shield plates are sprayed with a hydrophobic coating to eliminate this problem. We use a material made by the Vellox Corp. for this purpose. 7. Magnetic anomolies associated with steel hulled ships change with time. Automatic correction of the compass calibration is periodically done in the SEAWASP system using selected data from the GPS receiver. 8, One of the most important characteristics of any commercial temperature/humidity sensor is the manufacturer supplied filter which protects the delicate sensor elements from the environment and mechanical damage but lets air and water vapor pass freely through it. Rotronic Instrument Corp. has the best sensor/filter combination and the only unit that can maintain a +/- 2% calibration over a 1 year period in our application. 9. Electronics generally used to measure humidity are very susceptible to high humidities and are of a nature that is difficult to encapsulate. We have decided to place a dessicant within all electronics boxes topside. The humidity within these boxes is monitored with a dedicated humidity sensor and an alert message requesting that an operator replace the dessicant is displayed on the SEAWASP monitor in CIC.

Acknowledgement

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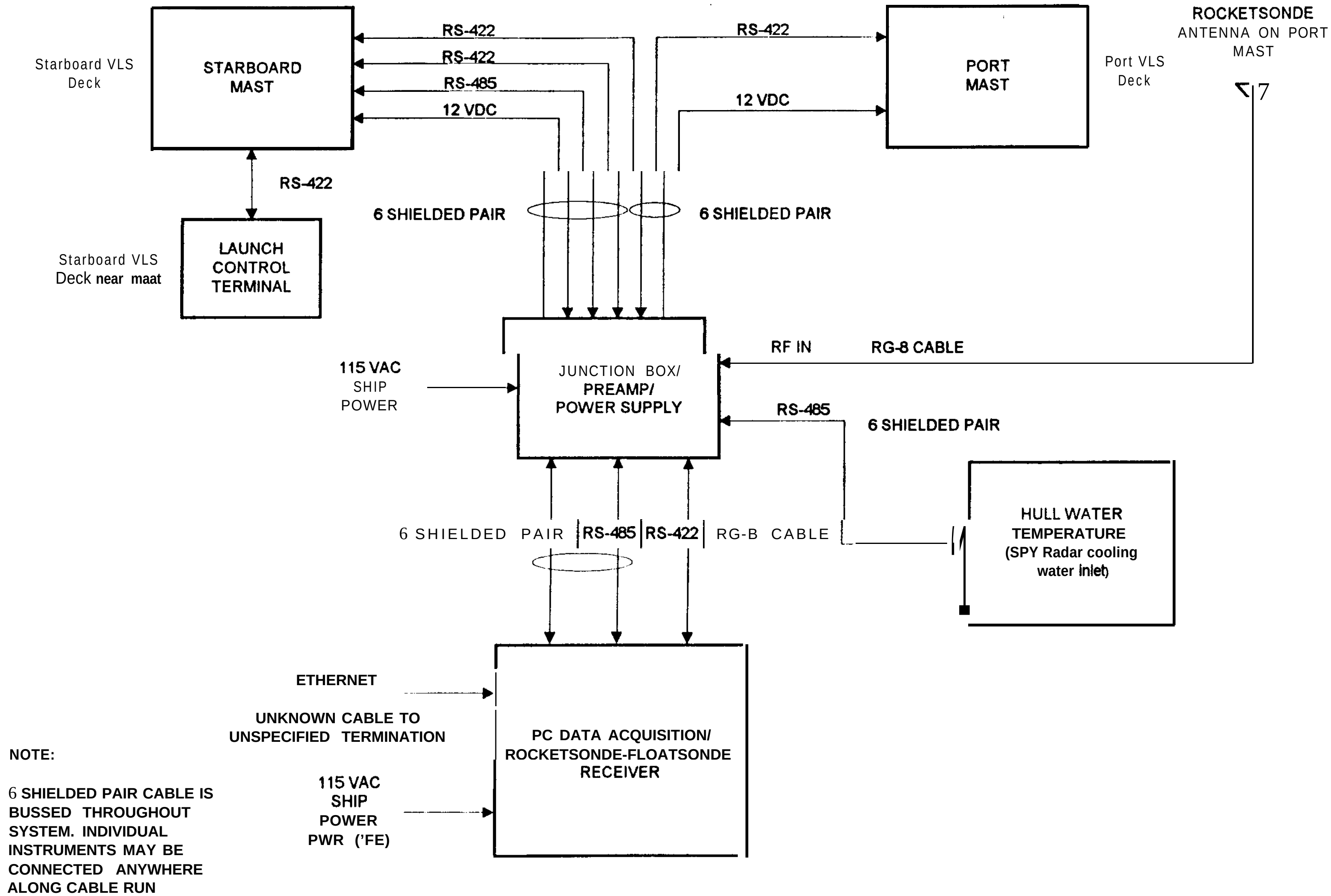

Figure 1: SEAWASP environmental system overview block diagram (USS Anzio CG-68)

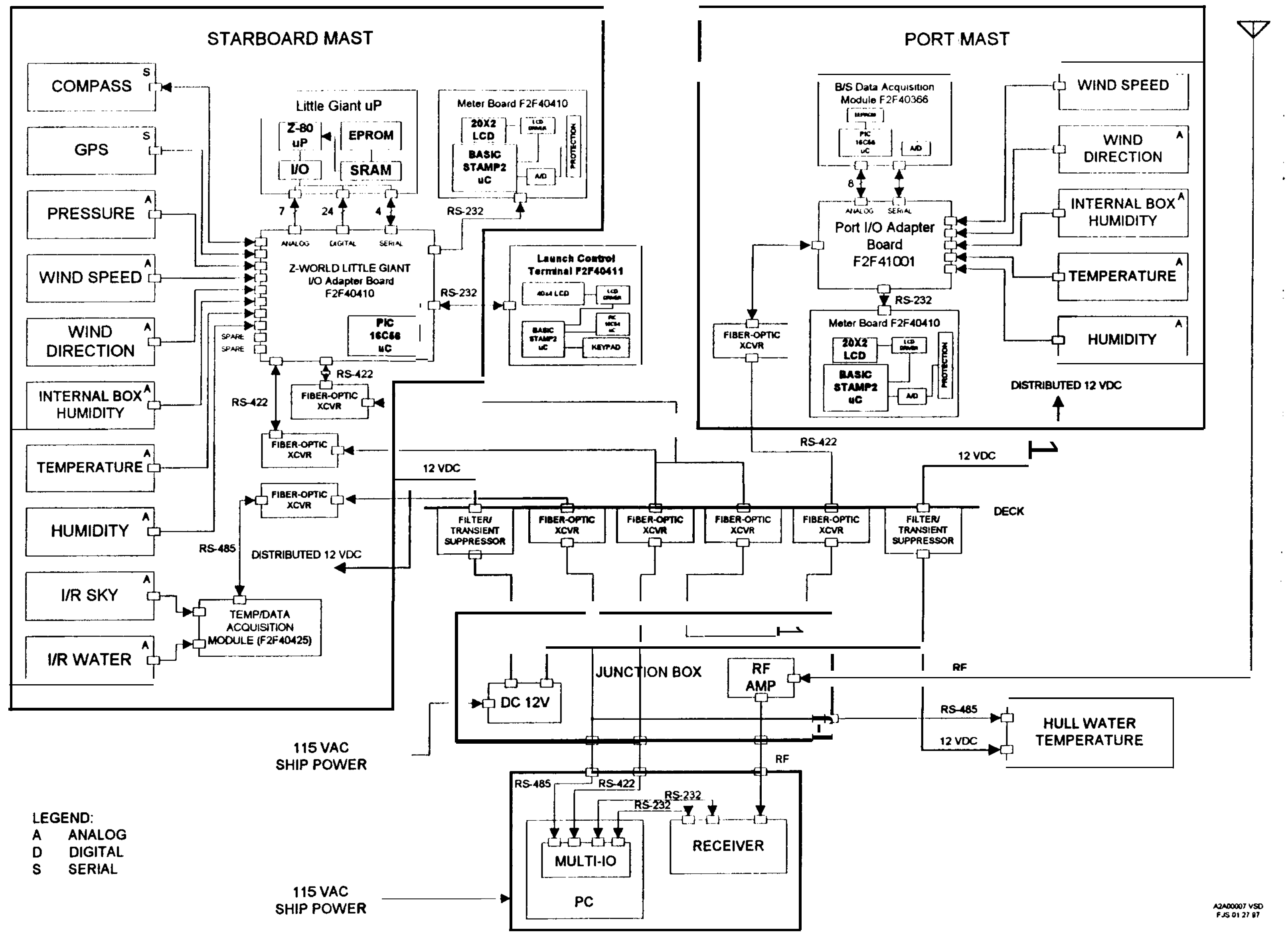

Figure 2: SEAWASP environmental system detailed block diagram (USS Anzio CG-68)

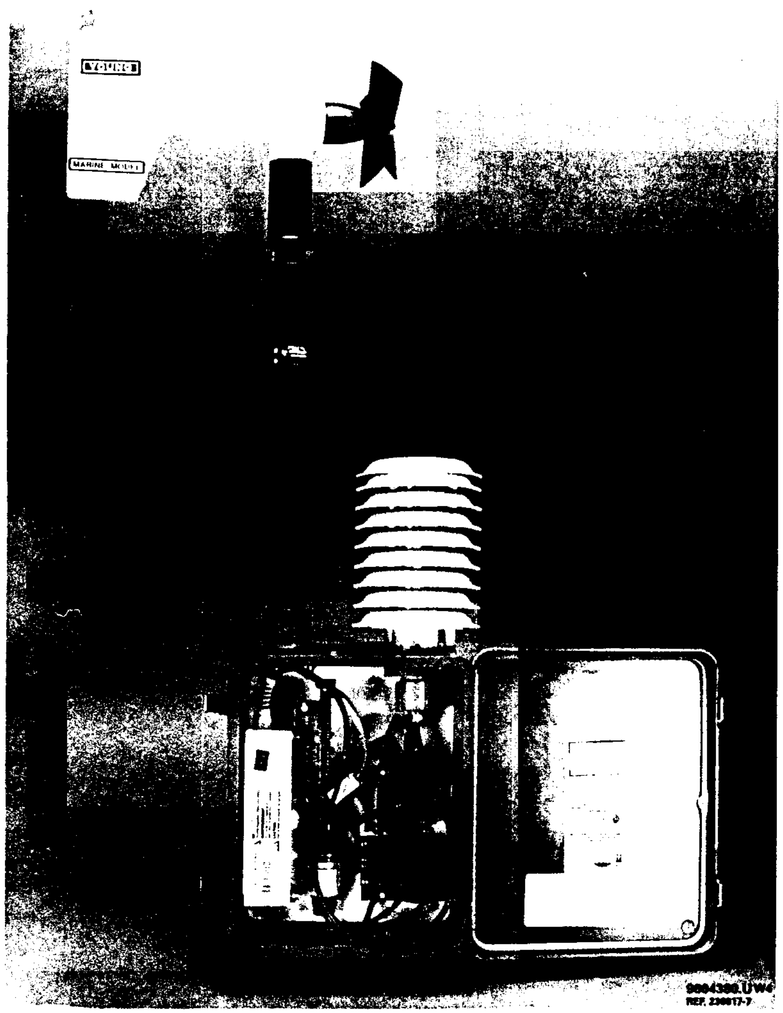

Figure 3: Port sensor mast electronics

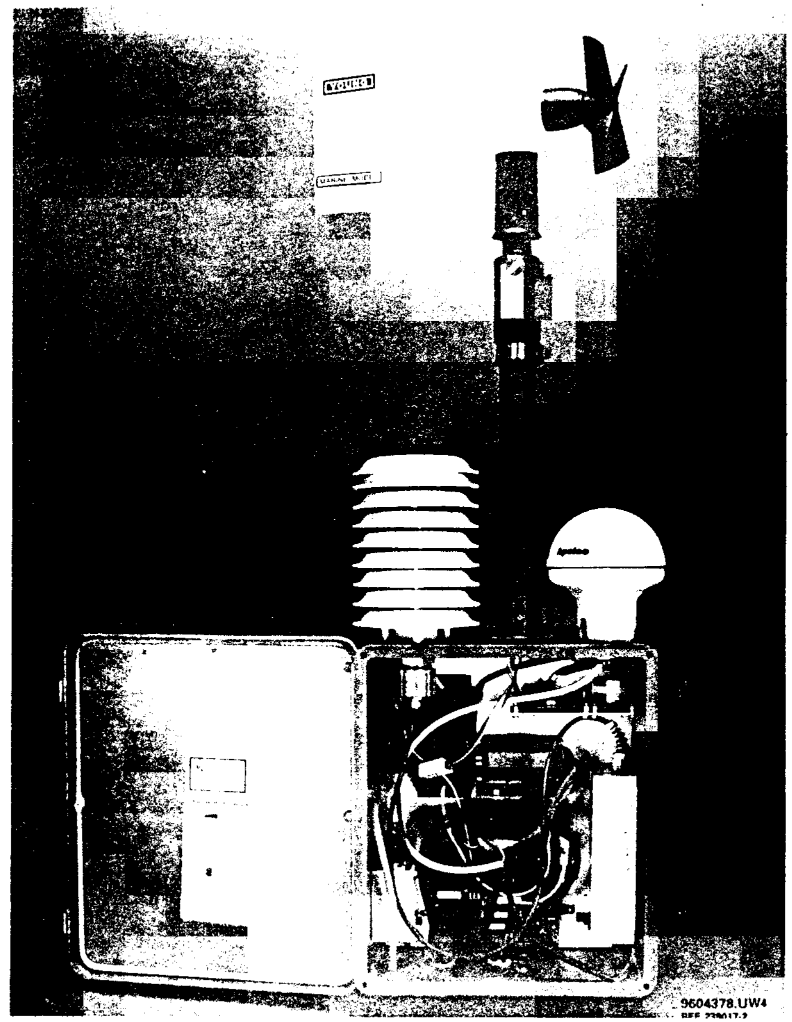

Figure 4: Starboard sensor mast electronics

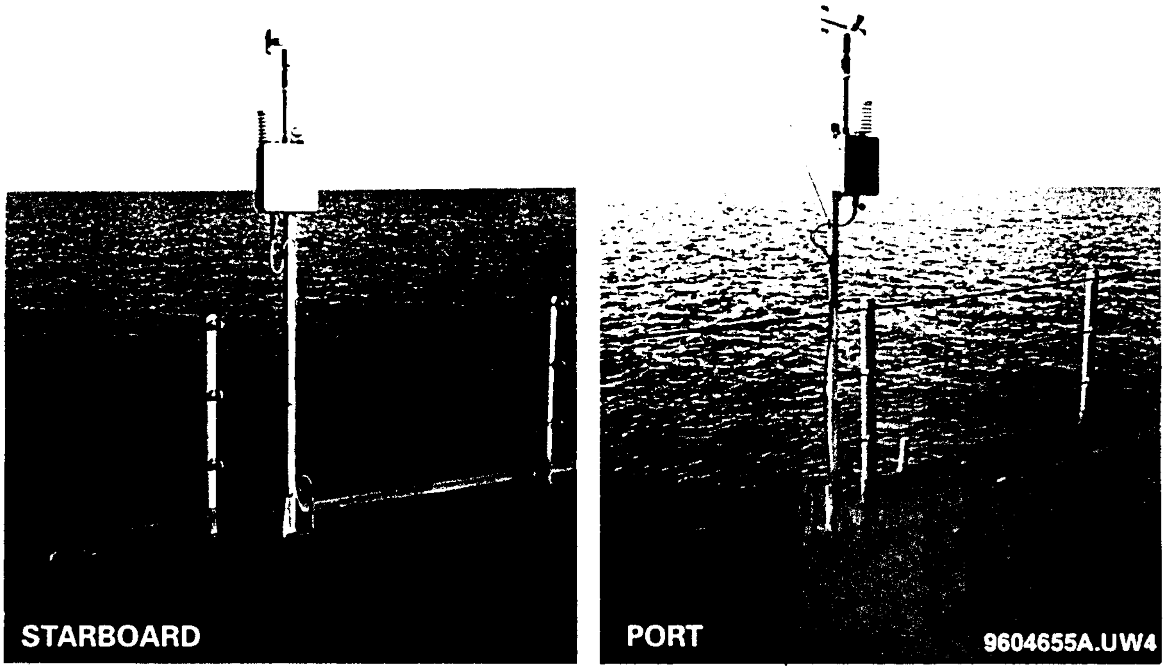

Figure 5: Port and starboard sensor masts installed onship

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Figure 6: Floatsonde

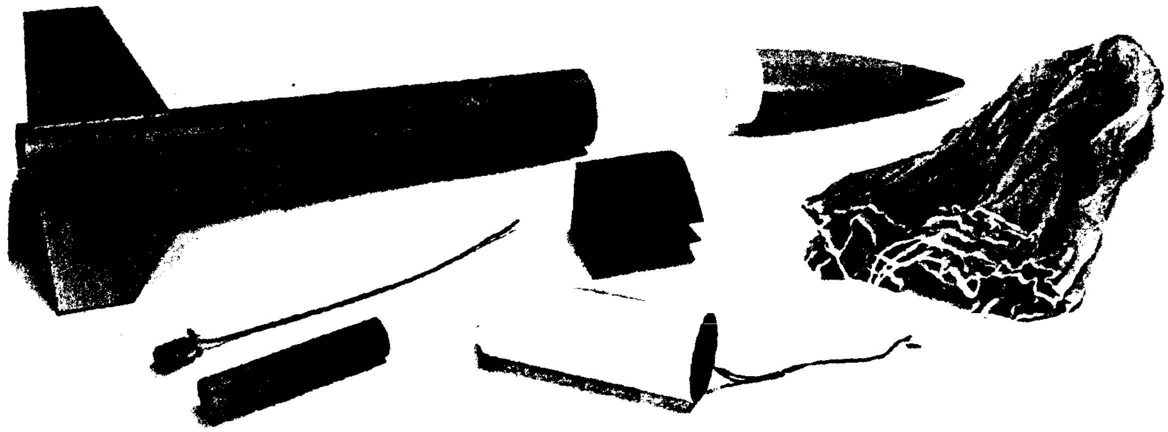

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Figure 7: Rocketsonde component parts including instrument package, parachute, rocket motor and igniter

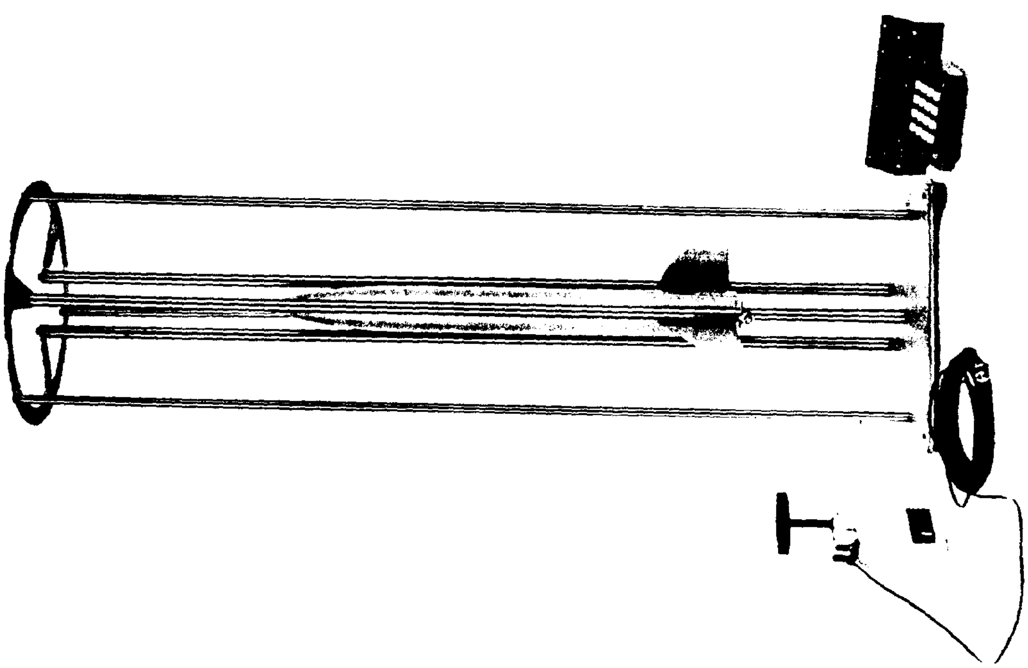

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Figure 8: Rocketsonde in launcher with ignition box and launch control terminal